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Effects of taxonomic group, spatial scale and descriptor on the relationship between human activity and stream biota

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ABSTRACT

Using human activity and stream biota data collected from 160 small (600–3000 ha) watersheds in rural southwestern Ontario, we determined the relative ability of three commonly used methods of describing fish and benthic macroinvertebrate assemblages (i.e., metrics, presence/absence, and relative abundance) to assess the biological effects of reach and basin scale human activity. Analyses indicated that benthic macroinvertebrate presence/absence was more strongly correlated with human activity at both reach and basin scales than fish presence/absence, benthic macroinvertebrate or fish relative abundance, and metrics derived from benthic macroinvertebrates or fish data. However, sites exhibiting lower levels of human activity were, in some cases, better differentiated by relative abundance. The use of metrics did not provide any additional information regarding the effects of human activities and regularly appeared to underestimate differences between moderately exposed sites and sites exposed to low or very high levels of human activity. Tests for redundancy between fish and benthic macroinvertebrates indicated that they respond differently to the same type and extent of human activity suggesting that the assemblages are sensitive to different stressors emanating from the same activities. There was also a disparity between assemblages with regards to which scale they were most strongly associated as fish were more associated with human activities at the basin scale whereas benthic invertebrates were most strongly associated with the activities at the reach scale. Finally, there was no apparent advantage to describing human activities at multiple scales as predicted basin scores were highly correlated among scales, a finding that may be attributable to the homogeneity of rural environments. Similar studies need to be conducted for a broader spectrum of human activities across a larger geographic extent to determine if these findings are widely applicable.

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1. Introduction

In aquatic environments, bioassessments are commonly conducted using one or more aquatic taxa, such as benthic macroinvertebrates (BMI) or fish (Rosenberg and Resh, 1993; Simon, 1999a,b). Biotic communities can be described using a wide variety of attributes, including the number of species present, their relative abundance, or other ecological attributes (Ricklefs and Miller, 1999). Indeed, the choice of method to describe the biota is one of the fundamental differences between multivariate and multi-metric approaches commonly used in aquatic bioassessment studies.

Multivariate approaches (e.g., RIVPACS [Wright, 2000] and BEAST [Reynoldson et al., 2000]) typically use either presence/absence or relative abundance data that describe the taxonomic composition of the community. The multi-metric approach (e.g., IBI [Karr, 1981] and B-IBI [Kerans and Karr, 1994]) uses a large number of indices or metrics that describe ecological attributes thought to be sensitive to the effects of human activities, followed by selection of a subset of indices that are most correlated to stressor gradients of interest (Gerritsen, 1995; Fore et al., 1996). Despite several studies comparing the ability of different approaches to evaluate ecological condition (e.g., Fore et al., 1996; Zamora-Muñoz and Alba-Tercedor, 1996; Reynoldson et al., 1997), there have been mixed results as to which is most effective, perhaps because of differences in how the biota are described rather than the assessment method itself. Given that change in ecological assemblages depends on the type and extent of human activity to which the ecosystem is exposed (Allan, 2004), the “best” way of describing the biota may depend on the combination of stressors present. Using both metrics and compositional descriptions of the biota may therefore add significant informa-

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tion and decision-making power to assessment and monitoring studies.

The taxonomic group(s) used in a bioassessment also affects the results (Mazor et al., 2006; Feio et al., 2007; Hughes et al., 2009). BMI are commonly used in both multivariate and multi-metric assessments of freshwater ecosystems around the globe (e.g., Barbour et al., 1999; Davies, 2000; Wright, 2000; Reynoldson et al., 2000). Fish have also been widely used for assessments with the multi-metric approach, especially in the United States (e.g., McCormick et al., 2001; Hughes et al., 2004; Lyons, 2006), and more recently in Europe (e.g., Breine et al., 2004; Magalhaes et al., 2008), as well as other parts of the world (e.g., Ganasan and Hughes, 1998; Bozzetti and Schulz, 2004; Joy and Death, 2004). Fish are also commonly used in multivariate based assessments, particularly within Australia and New Zealand (Joy and Death, 2002, 2003; deZwart et al., 2006; Kennard et al., 2006a; Chessman et al., 2008). Other biota, such as periphyton and macrophytes, are also used (e.g., Winter et al., 2003; Walker and Pan, 2006; Kelly et al., 2008), but less frequently than BMI or fish. The effect of the taxon used on the outcome of an assessment is important to determine because different taxonomic groups have been shown to vary in sensitivity to different stressors (Johnson et al., 2006) as have individual taxa and ecological characteristics within biotic groups (Compin and Cereghino, 2007; Wenger et al., 2008; Hutchens et al., 2009). Using a single group of organisms may therefore constrain the effectiveness of an assessment of the condition of freshwater ecosystems and as such the use of multiple assemblages has become common in some jurisdictions (e.g., European Union Water Framework Directive, European Commission, 2000).

The effectiveness of a taxon and the method with which it is described may also be influenced by the spatial scale at which the human activity being assessed is occurring. BMI and fish have been found to be most strongly associated to different scales (i.e., BMI to reach scale and fish to basin scale [Lammert and Allan, 1999;

Freund and Petty, 2007]). As such, variation in assessment results may also be attributable, at least in part, to where in an ecosystem human activity is occurring.

The purpose of this study was to measure the relationship between three methods of describing biota (i.e., metrics, presence/absence, and relative abundance) of two taxa (i.e., BMI and fish) with gradients of human activity at both the reach and basin scales. We answered three related questions after quantifying the strength and nature of these relationships.

- How are the strength and nature of associations between the biota and human activity gradients affected by choice of the descriptors of the biota (metric, presence/absence, relative abundance)?
- How are the strength and nature of associations between the biota and human activity gradients affected by choice of taxon (BMI, fish)?
- How are the strength and nature of association between the biota and human activity gradients affected by the geographic scale (reach, basin) of the analysis?

The results of this study will clarify how and how much the choice of descriptor(s) and taxon used add value to the assessment of the effects of human activity on aquatic ecosystems.

2. Methods

2.1. Study area

Southwestern Ontario is the southernmost part of Canada. It is almost completely encircled by the North American Great Lakes (Fig. 1), creating a warmer and more humid environment unique in Canada, with conditions and biota similar to areas much

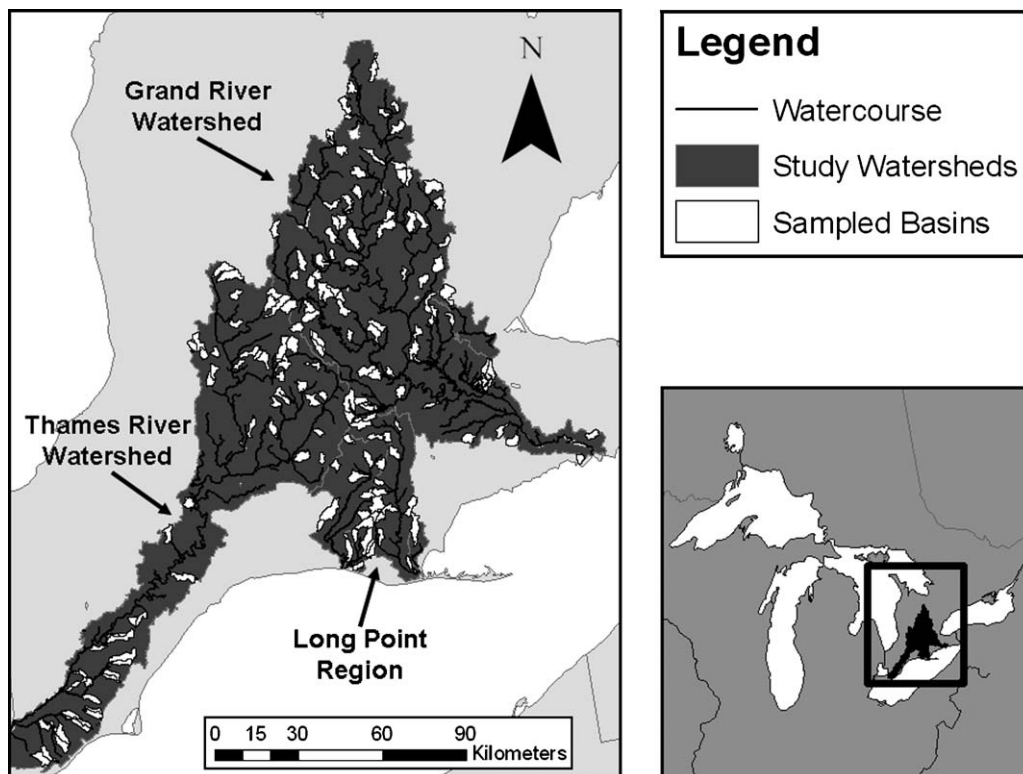


Fig. 1. Location of study area in Great Lakes Region, North America (lower right) and position of sampled rural headwater basins in their respective southwestern Ontario drainage basins (main).

further south. Geologically, the region is dominated by a wide variety of glacial deposits overlying calcium-carbonate rich Paleozoic bedrock. Vegetation in the region is characterized by deciduous forest; however most of this forest was removed following European settlement such that only small patches remain in most areas. While the region has several large urban centres, agriculture is the dominant land use by area, comprising approximately 75% of the region's land cover. Agriculture in the region tends to be a mixture of row crops (e.g., corn and soybeans) and high density livestock farms (e.g., beef, dairy, pork and poultry). Since initial, large-scale agricultural development in the late 19th and early 20th centuries there has also been substantial alteration of the region's hydrology as fields have been tile drained and streams have been channelized.

We analyzed data collected in the fall of 2006 and 2007 from 160 rural, headwater basins in three of the major drainage areas of southwestern Ontario (Fig. 1). Most of the basins were in the Thames River ($n=62$) and Grand River ($n=75$) watersheds, with the remaining 27 basins in four smaller watersheds that drain into the north shore of Lake Erie near Long Point Bay. Basins varied in size from 600 to 3000 hectares and were selected such that the full range of variation in rural human activity was represented. In contrast, the basins exhibited very little variation in most natural characteristics including stream size, bedrock geology, climate and altitude. Surface geology did, however, covary with human activity and as such was variable across the 160 basins.

2.2. Field sampling protocol

Fish and benthic macroinvertebrates (BMI) were sampled at each of the 160 basins between mid-September and late October of either 2006 or 2007. Sampling sites were established as close to the outflow of the basin as access allowed, with site lengths of 15–20 times stream bankfull width. Fish were sampled using a single pass with a backpack electrofisher at a rate of at least 10 shocking seconds per square metre of stream surface. Equating to a minimum of 600 shocking seconds per site. Easily identified fish were identified to species, counted and released. Unidentifiable fish were preserved in 70% ethanol and identified in the lab using a dissecting scope. BMI were collected using a three minute traveling kick and sweep with a 500 μm meshed D-net. Sampling time was divided amongst all the habitat types present (e.g., riffle, edge, pool, etc.) based on the proportion of the total sampling area that each individual habitat comprised. Collected samples were preserved in 90% ethanol and taken to the lab for processing. In the lab, samples were washed and all large debris removed. Washed samples were spread evenly across a pan comprised of 54 grid cells. Cells were randomly selected and the material removed and searched for invertebrates using a dissecting scope. This process was repeated until at least 300 individuals were subsampled or until the entire sample had been searched. Subsampled invertebrates were then identified to the lowest possible taxonomic level (usually genus).

2.3. Calculation of human activity gradient

Human activity at the reach scale that could potentially cause ecosystem degradation was summarized using the United States Environmental Protection Agency's rapid habitat assessment protocol for low gradient streams (Barbour et al., 1999). Because we were interested only in quantifying the extent and nature of activity, rather than its presumed effects, we only used the channel alteration, vegetative protection, and riparian zone sub-scores of the USEPA assessment. The covariance matrix of these sub-scores for the 160 sites was subjected to a Principal Component Analysis (PCA) to determine the main gradients of variation and covariation in human activity at the reach scale. The 1st PC axis, which explained more than 75% of the total variation at the reach scale,

revealed a prominent gradient of sites that varied from those with very little human alteration to sites with intensive activity and alteration.

Landscape scale stressors were described using the coarse, aspatial human activity gradient developed for the region by Yates and Bailey (2010a). This gradient was generated using GIS to describe activity in each basin including land use (e.g., % cropland) and land management (e.g., type and size of livestock farms) and synthesizes the types and extents of human activities present in 495 rural stream basins, including the 160 used in this study. These descriptors of human activity at the watershed scale were subjected to a PCA, which revealed a gradient of intensity of agricultural activity among the basins at the landscape scale explaining 30% of the total variation in human activity at the basin scale.

The PC score for each site from the first axis of the reach and basin PCAs was used to describe the extent of human activity for each of the 160 sites at the reach and basin scales, respectively.

2.4. Metric selection and analysis

BMI ($n=79$) and fish ($n=55$) metrics were calculated and tested for their degree of correlation to the human activity scores calculated for each site at the reach and basin scales (Appendix A). These metrics included commonly used measures of taxonomic richness, composition, tolerance, and function (Goldstein and Simon, 1999; Halliwell et al., 1999; Simon, 1999a,b; Coker et al., 2001; Mackie, 2001; Vieira et al., 2006). Although genus identifications were available for many individuals in the BMI samples many individuals of some taxa could only be identified to the family level. To prevent the exclusion of these individuals all taxa were described at the family level (exceptions included midges, crayfish, worms, and leeches which were included at the sub-family, order, class, and class levels, respectively). Family level resolution is commonly and effectively used in many bioassessment programs (Bailey et al., 2001; Reynoldson et al., 2001), however, it is recognized that this decision may have affected our ability to detect more subtle differences among samples (Lenat and Resh, 2001).

For both BMI and fish assemblages, Spearman rank correlations were used to determine which metrics were most correlated to the human activity gradients. To pass this test, metrics needed to have a Spearman rank correlation of $|r_s| > 0.30$ and an ecologically realistic association with at least one of the two gradients as demonstrated by a scatterplot. Although significant at the $p < 0.05$ level, the $|r_s| > 0.30$ as a metric selection criterion is lower than typically used by other studies (e.g., McCormick et al., 2001). Relaxation of this criterion was deemed appropriate as both activity gradients were truncated at the lower end due to widespread human activity across the region. Following this analysis, the level of redundancy among metrics correlated with human activity was also assessed using Spearman rank correlations. For pairs of metrics exhibiting a correlation of $|r_s| > 0.80$, the metric with the weakest association to the environmental gradients was removed. As a final check of metric sensitivity to human activity, ANOVAs ($p < 0.01$) were used to test each remaining metric's ability to distinguish between sites of high and low activity. Metric values for the 10% of the sites with the lowest activity scores were compared to the 10% of sites with the highest activity scores. All analyses used to select metrics were conducted using Systat (Version 11/Systat Software Inc./Richmond Point).

2.5. Comparison of descriptors, assemblages and scales

Organization of the assembled data resulted in eight data matrices, including two that described human activity at the reach and basin scales, and six that described the BMI and fish assem-

blages at each site using metrics (chosen as described above), presence/absence, and relative abundance of taxa that occurred at more than 5% of the sites.

To determine the strength of the relationship between the biota and the reach and basin scale human activity gradients, we used either Canonical Correspondence Analysis (presence/absence, relative abundance) or multiple linear regression (metrics). Canonical Correspondence Analysis (CCA) was used with compositional descriptors of the biota because CCA can detect unimodal relationships between environmental gradients and biota (ter Braak, 1995). Multiple linear regression (MLR) was used with metric descriptors of the biota because MLR is more suited for the detection of the assumed linear or monotonic relationships between the environmental gradients and metric descriptors. Both CCA and MLR produce an r^2 value that quantifies the amount of variation in the biota explained by variation in the human activity gradient. All CCAs were conducted using CANOCO (Version 4.55/Biometris – Plant Research International/Wageningen, The Netherlands). MLRs were conducted using Systat (Version 11/Systat Software Inc./Point Richmond).

From each of the 12 calculated (with MLR or CCA) relationships between human activity at the reach and basin scale and the three descriptors of fish and BMI communities, we calculated the predicted human activity of each site, hereafter called linear combination (LC) scores, from the measured biotic attributes (*sensu* Palmer, 1993). Scores for the attributes analyzed using CCA (i.e., presence/absence and relative abundance) were calculated using CANOCO (Version 4.55/Biometris – Plant Research International/Wageningen, The Netherlands), whereas scores for the metric based descriptions were calculated using the generated regression equations. The Pearson correlation between pairs of these 12 sets of LC scores quantified the degree and nature of redundancy of the relationships.

3. Results

3.1. Metric selection

Only 30 of the 79 candidate BMI metrics (Appendix A) had a Spearman rank correlation of $|r_s| > 0.30$. *Oligochaetes as a Proportion of Total Abundance* and *Crustacea and Mollusca as a Proportion of Total Richness* were removed because their negative relationships with human activity did not correspond to prevalent hypotheses regarding how these taxa respond to exposure to human activity (*sensu* Barbour et al., 1996). Only 11 of the remaining 17 metrics were not considered redundant after examination of pair-wise correlations, and of these, 10 (*Number of Diptera Families* [nDIPTERA ($F = 11.82, p = 0.002$)], the *Number of Intolerant Taxa* [nINTOL ($F = 42.17, p < 0.001$)], the *Number of Filterer Taxa* [nFILTER ($F = 11.56, p = 0.002$)], the *Number of Sprawler Taxa* [nSPRAWL ($F = 12.70, p = 0.001$)], *EPT as a Proportion of Total Richness* [ptEPT ($F = 45.13, p < 0.001$)], *Coleoptera as a Proportion of Total Richness* [ptCOLEOP ($F = 14.972, p = 0.001$)], *Tolerant Taxa as a Proportion of Total Richness* [ptTOLER ($F = 19.76, p < 0.001$)], *Swimmers as a Proportion of Total Richness* [ptSwim ($F = 34.26, p < 0.001$)], *Trichoptera as a Proportion of Total Abundance* [pTRICHOP ($F = 14.63, p = 0.001$)], *Modified Hilsenhoff's Family Biotic Index* [Hilsenhoff, 1988, MODFBI ($F = 18.04, p < 0.001$)] showed differences between average values of sites at the highest and lowest levels of human activity, and were used in further analyses.

Of the selected metrics ptCOLEOP, ptTOLER, ptSWIM, nFILTER, nSPRAWL and MODFBI were positively correlated with human activity at the reach scale, while pTRICHOP, nINTOL, nDIPTERA and ptEPT were negatively correlated with activity at the reach scale (Table 1). Five of the BMI metrics were also correlated with activity at the basin scale, but the correlations were weak relative to

Table 1

Spearman's rank correlation values between selected fish and benthic macroinvertebrate (BMI) metrics and human activity scores at the reach and basin scales.

Selected metric	Reach scale	Basin scale
Fish		
Coldwater Specialists as Proportion of Total Abundance	−0.401	−0.374
Herbivores as Proportion of Total Abundance	–	0.379
Micro-omnivores as Proportion of Total Abundance	–	0.323
Intolerants as Proportion of Total Abundance	−0.396	−0.324
Minnow Species as Proportion of Total Richness	–	0.362
BMI		
Number of Diptera Families	−0.322	−0.303
Trichoptera as Proportion of Total Abundance	−0.603	−0.339
EPT as Proportion of Total Richness	−0.594	−0.300
Coleoptera as Proportion of Total Richness	0.439	0.376
Number of Intolerant Taxa	−0.460	–
Tolerant Taxa as Proportion of Total Richness	0.571	–
Swimmers as Proportion of Total Richness	0.591	0.331
Number of Filterer Taxa	0.321	–
Number of Sprawler Taxa	0.383	–
Modified Hilsenhoff's Family Biotic Index	0.436	–

those with the reach scale. pTRICHOP, ptEPT, nDIPTERA were negatively associated whereas ptCOLEOP and ptSWIM were positively associated with basin scale activity (Table 1).

Of the 55 candidate fish metrics (Appendix B), only 18 had a Spearman rank correlation coefficient of $|r_s| > 0.30$ with either the reach or basin scale gradients of human activity. Contrary to expectations, the *Exotic Species as a Proportion of Total Abundance* metric decreased with increased human activity at both scales, and was therefore not used in further analyses. Ten of the remaining 18 metrics were highly correlated ($|r_s| > 0.80$) with other metrics, so the metric in the pair more weakly correlated with the activity gradients was removed from further analyses. Three of the eight remaining metrics showed no statistical difference ($p > 0.01$) between sites that were least and most exposed to human activity.

The final set of five metrics (Cyprinid Species as Proportion of Total Richness [psCYPR ($F = 19.15, p < 0.001$)], Intolerants as Proportion of Total Abundance [pINTOL ($F = 11.66, p = 0.002$)], Herbivores as Proportion of Total Abundance [pHERB ($F = 7.29, p = 0.01$)], Micro-omnivores as Proportion of Total Abundance [pMICRO ($F = 17.30, p < 0.001$)], Coldwater Specialists as Proportion of Total Abundance [pCOLD ($F = 7.68, p = 0.009$)] were considered the best descriptors of the biological effects of human activity, and were used in further analyses. Of these, psCYPR, pHERB, and pMICRO were positively associated with human activity at the basin scale, but not the reach scale (Table 1). pINTOL and pCOLD were negatively correlated with human activity at both the basin and reach scales.

3.2. Technique, assemblage, and scale comparisons

Results from the eight CCAs and four multiple regressions indicated that although the degree of association between the biota and the human activity gradients were significant in all cases (CCA: $p = 0.001$, Monte Carlo test with 1000 iterations; Regression: $p < 0.001$), there was substantial variability in the strength of the relationship depending on the method of describing the biota (metrics, presence/absence, or relative abundance), the taxon (BMI or

fish) and the scale of the activity gradient (reach or basin; Table 2). At the reach scale, BMI described with presence/absence of taxa had the strongest correlation with human activity and fish metrics the weakest. BMI presence/absence also had the strongest correlation with activity at the basin scale, but the BMI metrics were the least correlated to activity at this scale. In general, the BMI assemblage was most strongly correlated to human activity at the reach scale and fish assemblages were more strongly related to activity at the basin scale.

Linear combination (LC) site scores, which are the position of a site on the human activity gradient as predicted by the biota, showed significant redundancy among the biotic descriptors at the reach scale (Fig. 2). Predictions based on fish presence/absence and those generated using relative abundance were very highly correlated for both the reach and basin scale. Although still strongly

Table 2

Comparison of the proportion of variation in fish and benthic macroinvertebrate assemblages explained by human activity gradients at the reach and basin scales for three different modes (i.e., metrics, presence/absence and % composition) of assemblage description using species–environment r^2 -coefficients. Coefficients generated using Canonical Correspondence Analysis (CCA) for presence/absence and % composition data and multiple regression for metric data.

Biotic summary	Reach scale	Basin scale
Fish metrics	0.132	0.247
Fish presence/absence	0.278	0.410
Fish % composition	0.370	0.317
BMI metrics	0.444	0.156
BMI presence/absence	0.526	0.456
BMI % composition	0.449	0.344

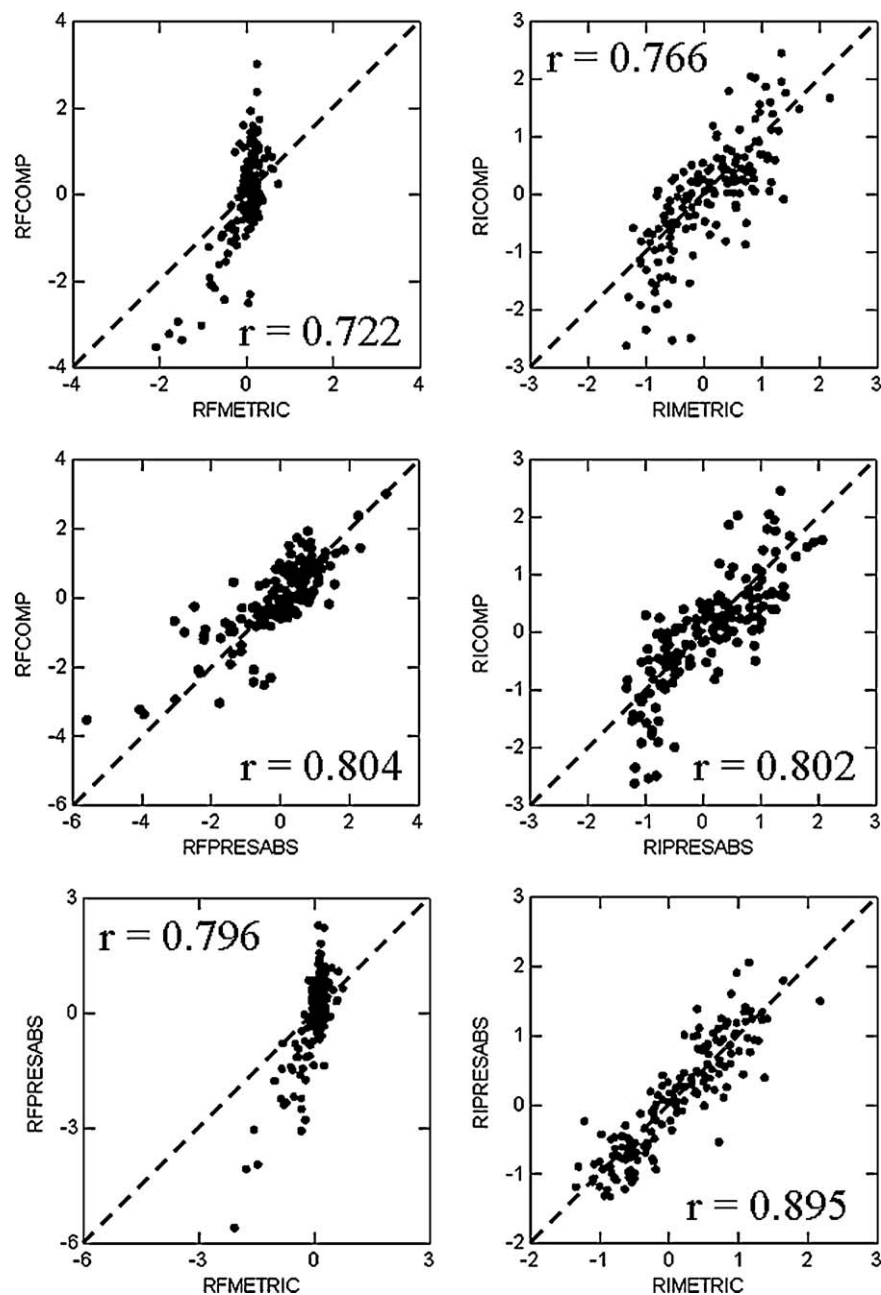


Fig. 2. Scatterplots comparing weighted average site scores calculated using reach (R) scale activity gradients and fish (F) or benthic macroinvertebrate (I) data summarized using different techniques (i.e., multimetrics (METRIC), presence/absence (PRESABS), and relative abundance (COMP)). Sites with the same score for both techniques would fall along the dashed line of equality. Note: higher scores represent sites exposed to greater levels of human activity.

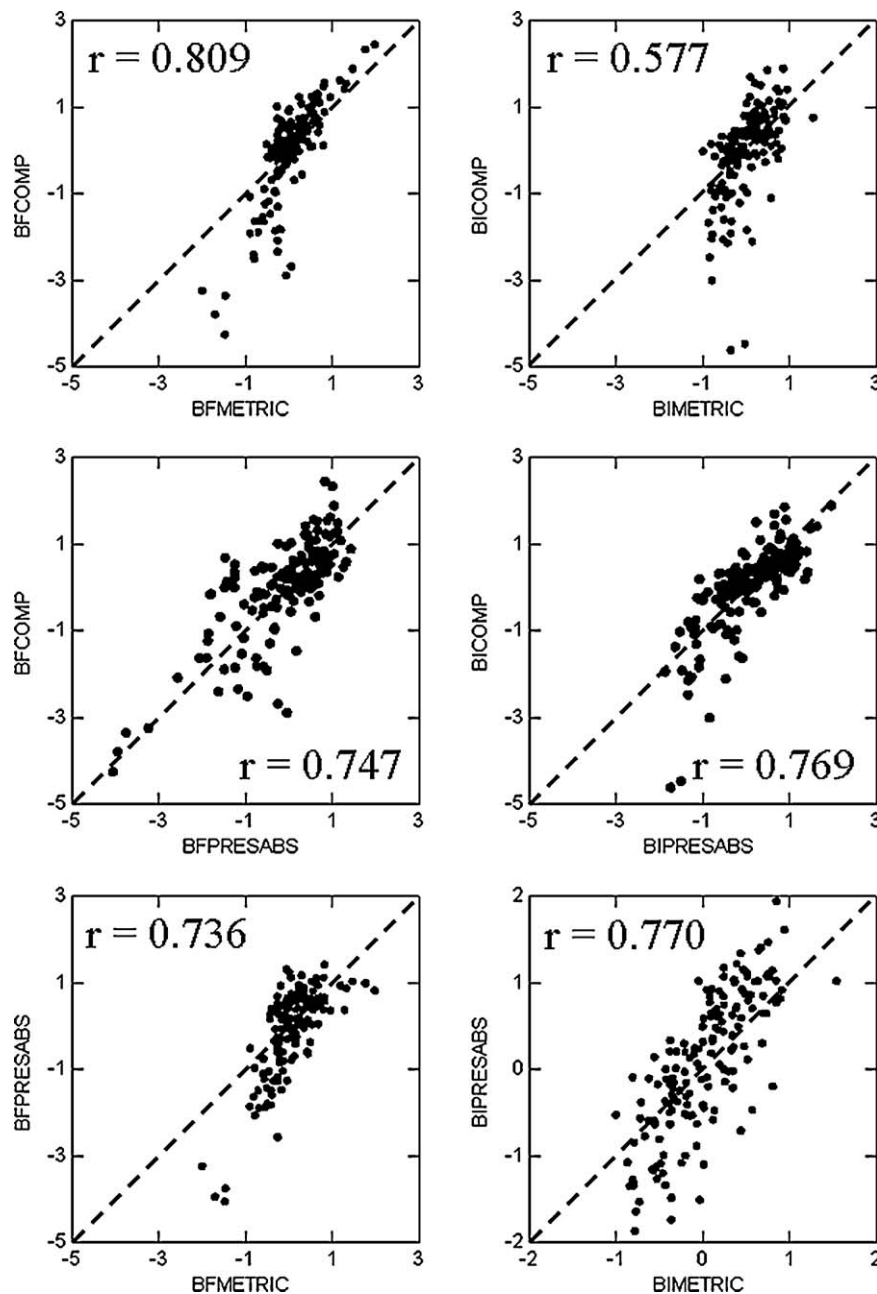


Fig. 3. Scatterplots comparing weighted average site scores calculated using basin (B) scale activity gradients and fish (F) or benthic macroinvertebrate (I) data summarized using different techniques (i.e., multimetrics (METRIC), presence/absence (PRESABS), and relative abundance (COMP)). Sites with the same score for both techniques would fall along the dashed line of equality. *Note:* higher scores represent sites exposed to greater levels of human activity.

correlated, there was less redundancy between metrics and the descriptors of taxonomic composition primarily due to differences at more extreme levels (both high and low) of activity where compositional descriptors consistently predicted greater differences from more moderately exposed sites than did their metric counterparts. Relative abundance and presence/absence site scores were also highly correlated for BMI assemblages, however, scores based on relative abundance discerned differences among sites at the low activity end of the gradient that scores based on presence/absence could not. There was also low correlation between scores derived from metrics and relative abundance of BMI. In contrast there was very high redundancy between metrics and presence/absence data at the reach scale.

Similar to the reach scale, the pattern of substantial redundancy between presence/absence and relative abundance descriptions of

the biota was also observed for both BMI and fish at the basin scale (Fig. 3). The tendency for descriptions based on composition to better discriminate differences in sites at the low activity end of the gradient was again seen at this scale for both BMI and fish. The disagreement between scores generated from metrics and those calculated from the compositional descriptors for both BMI and fish exhibited for the reach scale was also apparent in basin scale comparisons.

There were only modest correlations between the BMI and fish assemblages (Fig. 4). BMI and fish scores generated from metrics were least correlated for both reach and basin scale comparisons, whereas comparisons of presence/absence descriptions of the taxa were moderately correlated. Regardless of the method used to describe the biota, lower correlations between the BMI and fish assemblages were found at the basin scale relative to the reach

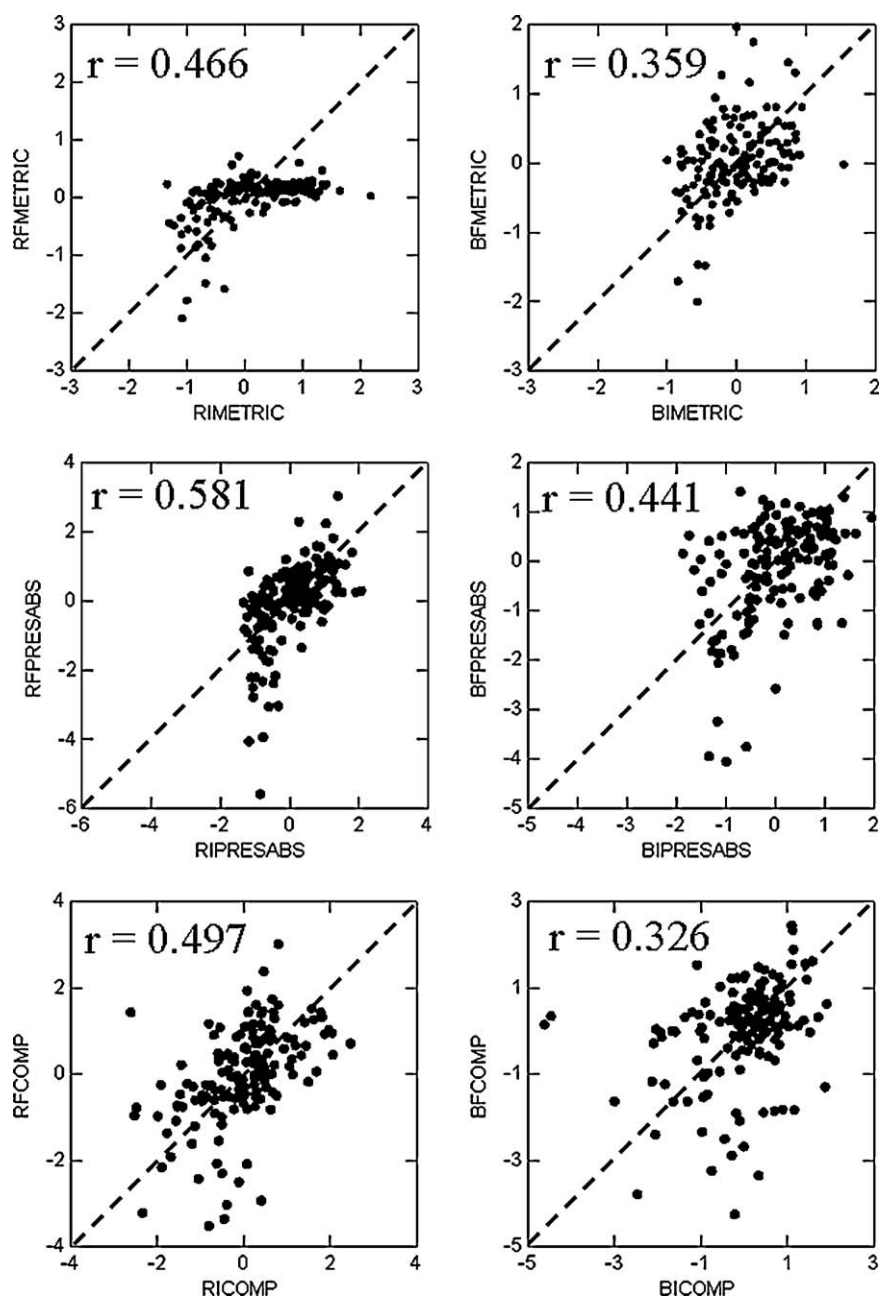


Fig. 4. Scatterplots comparing weighted average site scores that varied in the taxonomic group used (i.e., fish (F) and benthic macroinvertebrates (I)) while holding the data summary technique (i.e., multimetrics (METRIC), presence/absence (PRESABS), and relative abundance (COMP) and scale of human activity (i.e., basin (B) or reach (R) scale) constant. Sites with the same score for both taxa would fall along the dashed line of equality. *Note:* higher scores represent sites exposed to greater levels of human activity.

scale. BMI and fish communities were least redundant at sites exposed to lower extents of human activity. Fish assemblages at these sites were consistently more distinct from assemblages exposed to moderate and high levels of human activity compared to their BMI counter-parts. This pattern was particularly well demonstrated at the reach scale.

Comparison of LC scores that varied only in the scale of human activity (reach vs. basin) demonstrated a high level of redundancy (Fig. 5). This was particularly the case for BMI assemblages as they exhibited only minimal disagreement regardless of the method used to describe them or the extent of activity present. Predicted fish assemblage scores were slightly more variable when described as presence/absence or relative abundance but there was no consistent pattern to the deviations with regards to the extent of human activity.

4. Discussion

Human activities can manifest in a wide variety of chemical and physical changes to aquatic ecosystems (Allan, 2004). Because these effects seldom occur in isolation or impact all taxa in the same manner, the use of ecological assemblages, as opposed to single indicator taxa, has become common. In aquatic bioassessment, assemblages are usually described using either basic measures of taxonomic composition (e.g., presence/absence, relative abundance) or an integration of the community composition and other ecological information into metrics or indices. Assessment results using these different approaches frequently disagree on the presumed condition of an aquatic ecosystem (Fore et al., 1996; Zamora-Muñoz and Alba-Tercedor, 1996; Reynoldson et al., 1997). One reason for this difference may be that the methods of describ-

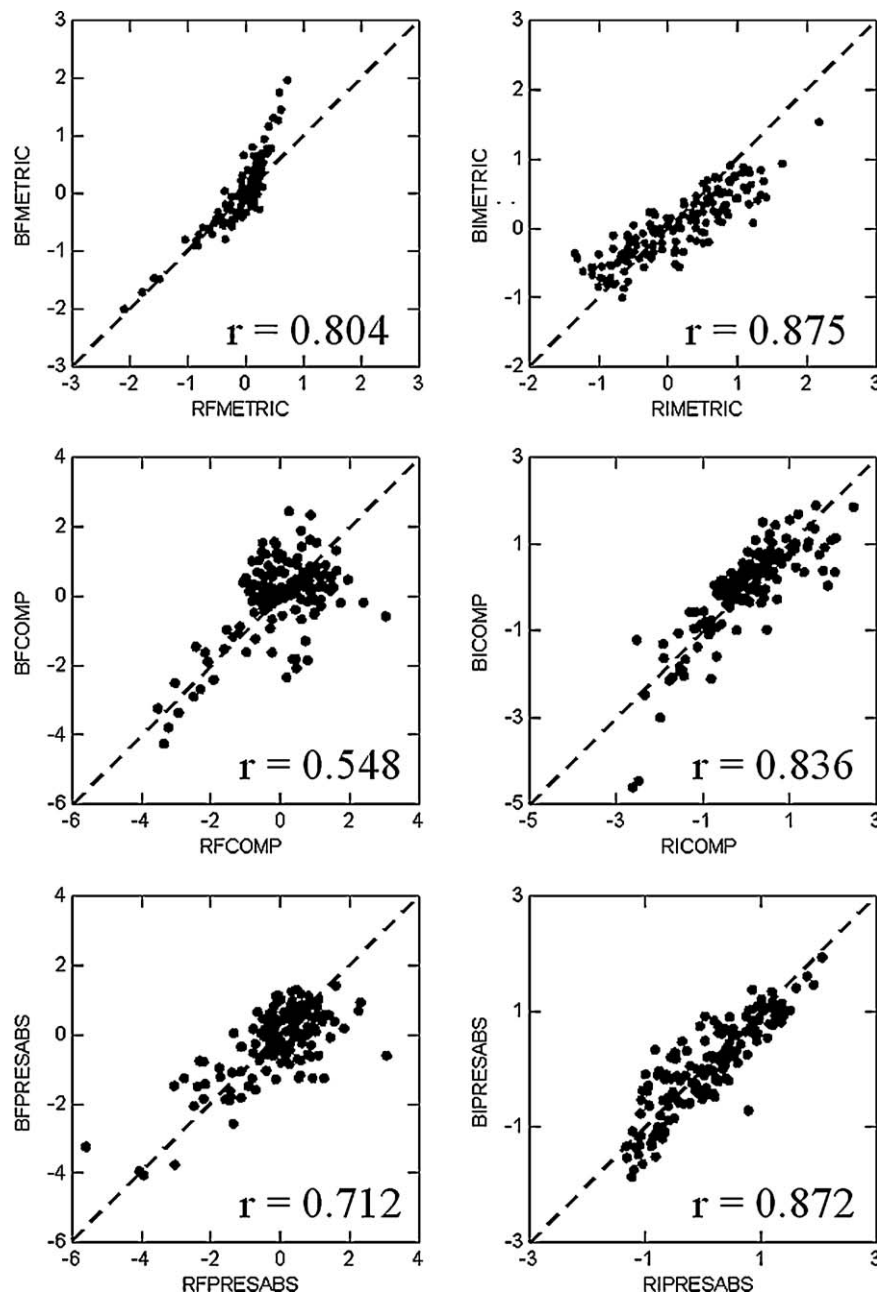


Fig. 5. Scatterplots comparing weighted average site scores that varied in the scale of human activity used (i.e., basin (B) or reach (R) scale) while holding the data summary technique (i.e., multimetrics (METRIC), presence/absence (PRESABS), and relative abundance (COMP) and taxonomic group (i.e., fish (F) and benthic macroinvertebrates (I)) constant. Sites with the same score for both scales would fall along the dashed line of equality. *Note:* higher scores represent sites exposed to greater levels of human activity.

ing the biota vary with regards to their sensitivity to detect the effects of particular types and extents of human activity.

Past studies have found taxonomic composition to be more strongly correlated with human stressor gradients than metrics (e.g., Cao et al., 1996), but these studies have not compared descriptions of taxonomic composition with the multiple metrics most commonly used in bioassessment (Barbour et al., 1996). The purpose of multiple metrics is to enhance determination of ecological condition through the integration and reduction of the many data on the structure and function of assemblages (Gerritsen, 1995). In this study, descriptions of the biota that depict the composition of the entire assemblages but do not explicitly incorporate other ecological knowledge about taxa (e.g., functional attributes) were more strongly correlated with human activity than metrics for both

BMI and fish at both the reach and basin scale. This contradicts the expectation that carefully selecting metrics based on their relationships with the activity gradients would give metrics an advantage over the less processed and perhaps “noisier” presence/absence and relative abundance descriptors, but conforms with the suggestion that the metric selection process may lead to loss of important ecological information (Norris, 1995).

Functional characteristics or traits of organisms respond to changes in human activity (Statzner et al., 2001), and have been shown to outperform compositional measures in their sensitivity to ecosystem degradation (Dolédéc et al., 2006). However, despite the fact that a third of the selected metrics described functional attributes, as a group they had the weakest relationships with gradients of human activity. Although this result suggests that func-

tional attributes are not as effective it is also possible that the traits used were perhaps not best suited to detecting the effects of the activities present in the study region. Other traits, such as body size, respiration type and reproductive cycle, have been shown to be effective at detecting the effects of human activity (e.g., Dolédec et al., 2006; Dolédec and Statzner, 2008; Statzner and Bêche, 2010) and may have been more strongly associated with changes in the intensities of the measured human activities. Understanding of traits as indicators of ecological condition is still, however, in its infancy and although knowledge of the functional characteristics of many taxa is rapidly improving with the development of immense databases (e.g., Vieira et al., 2006), there is still a great number of taxa and traits that have not received adequate attention (Culp et al., 2010). The effectiveness of traits should continue to be explored as research sheds more light on which traits are best able to detect the effects of specific human activities.

Decisions with regards to sampling design and intensity may also have been an important factor in our results. Our sampling effort was similar to that commonly recommended in Canadian bioassessment programs (i.e., Family identifications and minimum 300 count subsamples for BMI [Reynoldson et al., 1999]). Bioassessment protocols are, however, aimed at providing a snapshot of stream conditions and often use less intensive sampling methods that have been shown to result in significant error in the estimates of assemblage attributes (e.g., Vinson and Hawkins, 1996; Kennard et al., 2006b). The actual sampling precision is likely to be highest for the integrated descriptors, such as taxonomic composition or taxon richness, and is likely to be much less precise for more specific descriptors, such as proportion of herbivores or filter feeders. Although it is beyond the scope of this study, further research needs to be conducted as to how the error introduced by sampling varies among descriptors of the biota.

In addition to being less correlated with the extent of human activity than presence/absence or relative abundance descriptors, our results suggest that metrics contribute little additional information relative to descriptions of composition. Relative abundance did, however, frequently detect differences among sites with lower levels of human activity that presence/absence did not, suggesting that presence/absence data alone are not well suited for the detection of subtle differences in the intensity of human activity. This conclusion is consistent with the expected response of assemblages to increasing levels of exposure to human stressors (Davies and Jackson, 2006). For example, when exposure is at low levels and the impact on receiving assemblages is small, there are minor changes in the relative proportion of taxa, but little or no loss of taxa. Because these changes are reflected in relative abundance data, these descriptions are able to detect differences at low levels of exposure when presence/absence data cannot. However, as the exposure to human activity increases, the loss of taxa becomes the predominant change in the assemblage. Examples of this predictive response of biota to human activity has been demonstrated in studies comparing BMI assemblages at varying distances from point sources (e.g., Boyle and Fraleigh, 2003).

Overall, our results suggest that different descriptors of biotic assemblages do vary in their ability to detect the effects of human activity. However, there does not appear to be any advantage to using metrics in addition to compositional descriptors. Indeed, our findings suggest that using metrics may result in less effective assessments as metrics frequently predicted little difference between sites exposed to low and very high levels of human activity. In contrast, relative abundance data may be the best overall descriptor from the perspective that it can detect the effects of more subtle differences in human activity.

Fish and BMI have often been considered to respond to human activities at different scales, with fish being most responsive to drivers acting at the basin scale and BMI being more indicative of

reach scale drivers (Plafkin et al., 1989). The results of this study only partially support this assertion. In support is our finding that fish were most correlated with human activity at the basin scale, whereas BMI were most correlated with the reach scale. However, the correlations between human activity at the basin scale and BMI were stronger than those with fish when presence/absence or relative abundance data were used to describe the BMI. Interestingly, of the few other studies that have compared the relationships of fish and BMI with human activity at different scales, those using metrics have found that fish are more responsive to larger scales and BMI more responsive to smaller scales (e.g., Lammert and Allan, 1999; Freund and Petty, 2007). By comparison, when species abundance data was used in a study by Johnson et al. (2007), only marginal differences were found between the responses of the assemblages to large and small scales. Our results suggest that the conflicting results of these past studies are at least partially attributable to the technique used to describe the biota.

The moderate correlations between LC scores resulting from comparisons of fish and BMI suggest that these two taxa are both providing useful information towards the assessment of human activity. This finding is consistent with other studies that have demonstrated frequent disagreement between fish and BMI regarding the condition of an ecosystem, especially at low to moderate levels of human activity (Paller, 2001; Freund and Petty, 2007). Fish and BMI assemblages have frequently been found to be correlated with similar suites of environmental variables (Kilgour and Barton, 1999; Yates and Bailey, 2010b), however, the nature and relative strength of these associations are often quite different (Lammert and Allan, 1999; Hering et al., 2006). The findings of these previous studies may be attributable to the fact that in a multiple stressor environment, such as the one in this study, each assemblage may be responding to a different aspect of the same activity to which they are most sensitive. An example of this difference in sensitivity was shown by Johnson et al. (2006) who found that BMI were most responsive to nutrient addition whereas fish tended to be driven by changes in the hydrologic regime. As such, using multiple assemblages should increase the likelihood that assessments provide an overall picture of the effects of human activities on ecological condition. Furthermore, a multiple assemblage approach should also ensure that the overall condition of an ecosystem is not masked by improvements following mitigation of a single stressor.

Our findings suggest differences in the manner by which fish and BMI respond to the effects of human activity. Specifically, our results indicated that BMI responded at a gradual, but continuous, rate across the range of extent of human activity present in the region, however, fish assemblages appeared to undergo a substantive shift in condition when human activity reached moderate levels. This shift is consistent with the often widespread change in composition that is seen when human activities initiate a change from cold to warm thermal regimes causing the loss of the cold-water specialists and their replacement by warm water tolerant species (Hughes et al., 2004). Other studies have also found this threshold point to be reached at relatively modest levels of human activity (Marshall et al., 2008). Overall, our study provides further support for the use of complementary taxonomic groups, such as fish and BMI, for the purpose of increasing the effectiveness of assessments through enhanced detection of the effects of human activity.

Of the three factors tested in this study, the scale at which human activity was occurring had the smallest affect on how the biota predicted a site's location on the human activity gradient. This result was somewhat surprising, as the extent of activity at the basin scale was only moderately correlated with activity occurring at the reach scale ($r=0.398$). Given this modest correlation and the fact that the activities summarized at the reach and basin scales were of

different, albeit related types, we did not expect a strong correlation between the predicted site scores. Our finding may be due to the fact that although the activities described in the gradients are different, the effects these activities have on biota tend to be similar (compare Stauffer et al., 2000 and Wang et al., 1997). This explanation is supported by the fact that results indicated that the taxa/metrics most related to the human activity gradients tended to be similar for both scales. Another consideration is the fact that basins with very low levels of human activity were not well represented in either gradient, limiting our ability to test the effects of scale as comparisons for opposite extremes (e.g., very high activity at the reach scale vs. very low activity at the basin scale) and for very low exposure at both scales. However, findings by other studies that aquatic biota are frequently sensitive to human activities at multiple scales (e.g., Strayer et al., 2003) suggests that similar results may have been obtained even for these missing scenarios. Overall, our results indicate that the use of separate scale specific gradients adds little value to assessments of small, rural streams in southwestern Ontario.

5. Summary

BMI presence/absence data explained the greatest amount of variation in the extent of human activity at both the reach and basin scales in rural, southwestern Ontario streams. However, presence/absence descriptions did not detect differences among sites that other taxa descriptions did at lower extents of human activity. Because relative abundance descriptions were consistently able to separate sites that had subtle differences in the extent of human activity at the low extremes and were generally well correlated with human activity at both the reach and basin scales for both fish and BMI, it appears to be the best single method of describing the biota. Metrics exhibited weaker relationships with human activity gradients and demonstrated little potential to add information to an assessment beyond what the other descriptions offered. In contrast, where appropriate, future bioassessment protocols for this region and other similar regions should incorporate both fish and BMI as

each group provides unique information regarding the effects of human activity. Unfortunately, using both fish and BMI does require substantial increases in resources for either sampling of fish or laboratory time for sub-sampling and identification of BMI. Given how differently fish and BMI often scored sites in this study we believe the extra resource expenditure to be worthwhile. If, however, only one assemblage can be sampled, our results suggest that it be BMI as this assemblage correlated strongly with human activity at both scales when summarized using presence/absence or relative abundance data. Finally, the modest effects of geographic scale suggests that a single, aggregated gradient of human activity should be sufficient in areas where the activities are expected to cause similar changes in the aquatic ecosystem. Studies incorporating more variation in the types and degrees of human activities (e.g., rural and urban activities) should be conducted to ensure the effects of scale found in this study can be applied to areas dominated by other types of human activity.

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Appendix A.

Calculated benthic macroinvertebrate metrics to which the metric selection process was applied. “F” denotes the test that each metric failed and “P” denotes those selected.

Metric	Correlation	Redundancy	Sensitivity	Selected
Relative Density	F			
Total Taxa Richness	F			
Number of Empheroptera Families	F			
Number of Trichoptera Families		F		
Number of Plecoptera Families		F		
Number of EPT Families		F		
Number of Coleoptera Families		F		
Number of Odonata Families	F			
Number of Diptera Families				P
Number of Crustacea and Mollusca Taxa	F			
Number of Hydraacarina Families	F			
Number of Intolerant Taxa				P
Number of Tolerant Taxa		F		
Number of Scraper Taxa	F			
Number of Predator Taxa	F			
Number of Gatherer Taxa	F			
Number of Filterer Taxa				P
Number of Shredder Taxa	F			
Number of Tropic Guilds	F			
Number of Clinger Taxa		F		
Number of Climber Taxa	F			
Number of Swimmer Taxa		F		
Number of Sprawler Taxa				P
Number of Burrower Taxa	F			
Number of Habitat Guilds	F			
Ephemeroptera as Proportion of Total Richness	F			
Plecoptera as Proportion of Total Richness		F		
Trichoptera as Proportion of Total Richness		F		
EPT as Proportion of Total Richness				P
Coleoptera as Proportion of Total Richness				P

Appendix A (Continued)

Metric	Correlation	Redundancy	Sensitivity	Selected
Odanata as Proportion of Total Richness	F			
Diptera as Proportion of Total Richness	F			
Crustacea and Mollusca as Proportion of Total Richness	F			
Chironomidae as Proportion of Total Richness	F			
Hydracarina as Proportion of Total Richness	F			
Tolerant Taxa as Proportion of Total Richness				P
Intolerant Taxa as Proportion of Total Richness		F		
Scrapers as Proportion of Total Richness	F			
Predators as Proportion of Total Richness	F			
Gatherers as Proportion of Total Richness	F			
Filterers as Proportion of Total Richness	F			
Shredders as Proportion of Total Richness	F			
Clingers as Proportion of Total Richness			F	
Climbers as Proportion of Total Richness	F			
Swimmers as Proportion of Total Richness				P
Sprawlers as Proportion of Total Richness		F		
Burrowers as Proportion of Total Richness	F			
Dominant Taxon as Proportion of Total Abundance	F			
Oligochaeta as Proportion of Total Abundance	F			
Odanata as Proportion of Total Abundance	F			
Emphemeroptera as Proportion of Total Abundance	F			
Trichoptera as Proportion of Total Abundance				P
Plecoptera as Proportion of Total Abundance		F		
EPT as Proportion of Total Abundance		F		
Coleoptera as Proportion of Total Abundance	F			
Diptera as Proportion of Total Abundance	F			
Chironomidae as Proportion of Total Abundance	F			
Orthocladinae as Proportion of Total Abundance	F			
Tanytarsininae as Proportion of Total Abundance	F			
Crustacea and Mollusca as Proportion of Total Abundance	F			
Bivalvia as Proportion of Total Abundance	F			
Amphipoda as Proportion of Total Abundance	F			
Isopoda as Proportion of Total Abundance	F			
Intolerant Taxa as Proportion of Total Abundance		F		
Tolerant Taxa as Proportion of Total Abundance		F		
Scraper Taxa as Proportion of Total Abundance	F			
Predator Taxa as Proportion of Total Abundance	F			
Gather Taxa as Proportion of Total Abundance	F			
Filterer Taxa as Proportion of Total Abundance		F		
Shredder Taxa as Proportion of Total Abundance	F			
Clinger Taxa as Proportion of Total Abundance	F			
Climber Taxa as Proportion of Total Abundance	F			
Swimmer Taxa as Proportion of Total Abundance		F		
Sprawler Taxa as Proportion of Total Abundance	F			
Burrower Taxa as Proportion of Total Abundance	F			
Modified Hilsenhoff's Family Biotic Index				P

Appendix B.

Calculated fish metrics to which the metric selection process was applied. “F” denotes the test that each metric failed and “P” denotes those selected.

Metric	Correlation	Redundancy	Sensitivity	Selected
Number of Native Species	F			
Number of Species	F			
Number of Native Families	F			
Number of Benthic Species	F			
Number of Intolerant Benthic Species	F			
Number of Water Column Species	F			
Number of Intolerant Species		F		
Number of Tolerant Species	F			
Number of Reproductive Guilds	F			
Number of Trophic Guilds	F			
Number of Sunfish Species	F			
Number of Salmon Species		F		
Number of Perch Species	F			
Number of Minnow Species		F		
Number of Tolerant Minnow Species		F		
Number of Species to Make 80% of Total Richness	F			
Number of Fish	F			
Benthic Species as Proportion of Total Richness	F			
Intolerant Benthic Species as Proportion of Total Richness	F			
Water Column Species as Proportion of Total Richness	F			
Intolerant Species as Proportion of Total Richness		F		

Appendix B (Continued)

Metric	Correlation	Redundancy	Sensitivity	Selected
Tolerant Species as Proportion of Total Richness	F			
Sunfish as Proportion of Total Richness	F			
Salmon as Proportion of Total Richness		F		
Perch as Proportion of Total Richness	F			
Sucker as Proportion of Total Richness	F			
Sculpin as Proportion of Total Richness		F		
Minnow as Proportion of Total Richness				P
Tolerant Minnows as Proportion of Total Richness		F		
Proportion of Species to Make 80% of Total Richness	F			
Coldwater Specialists as Proportion of Total Abundance				P
Coolwater Specialists as Proportion of Total Abundance	F			
Benthic Species as Proportion of Total Abundance	F			
Intolerant Benthic Species as Proportion of Total Abundance	F			
Water Column Species as Proportion of Total Abundance	F			
Lunkers as Proportion of Total Abundance	F			
Exotics as Proportion of Total Abundance	F			
Intolerants as Proportion of Total Abundance		F		
Tolerants as Proportion of Total Abundance	F			
Benthic Invertivores as Proportion of Total Abundance			F	
Insectivores as Proportion of Total Abundance			F	
Invertivores as Proportion of Total Abundance				P
Piscivores as Proportion of Total Abundance			F	
Herbivores as Proportion of Total Abundance				P
Micro-omnivores as Proportion of Total Abundance				P
Macro-omnivores as Proportion of Total Abundance	F			
Omnivores as Proportion of Total Abundance	F			
Nest Builders as Proportion of Total Abundance	F			
Egg Broadcasters as Proportion of Total Abundance	F			
Egg Attachers as Proportion of Total Abundance	F			
Nest Guardians as Proportion of Total Abundance	F			
Gravel Spawners as Proportion of Total Abundance	F			
Sculpins as Proportion of Total Abundance		F		
Dominant specie as Proportion of Total Abundance	F			
Three Dominant species as Proportion of Total Abundance	F			

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